Technology Solutions: Creating a Sustainable Biofuels Future

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UOP LLC

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A Honeywell Company

- Leading supplier and licensor of process technology, catalysts, adsorbents, process plants, and technical services to the petroleum refining, petrochemical, and gas processing industries
- UOP technology furnishes 60% of the world's gasoline, 85% of the world's biodegradable detergents, and 60% of the world's *para*-xylene
- Strong relationships with leading refining and petrochemical customers worldwide
- UOP's innovations enabled lead removal from gasoline, biodegradable detergents, and the first commercial catalytic converter for automobiles

2003 National Medal of Technology Recipient

Biofuels: Next in a Series of Sustainable Solutions

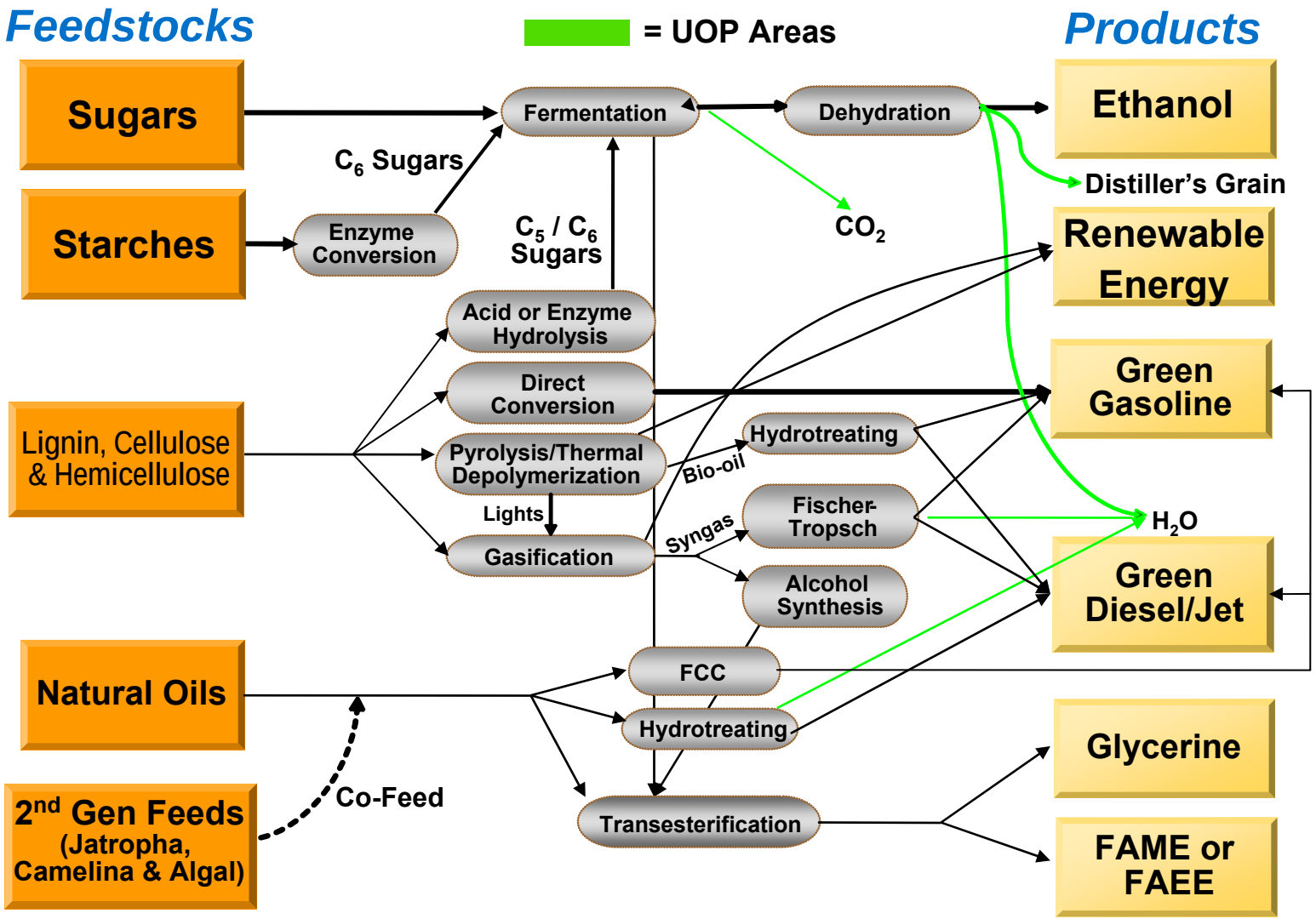
Macromarket Summary: Through 2015

- **Global energy demand is expected to grow at CAGR 1.6%.**
  - **Feedstock diversity will become increasingly important over this period with coal, natural gas & renewables playing bigger roles.**
- **Fossil fuels are expected to supply 83% of energy and 95% of liquid transportation needs**
- **Biofuels are expected to grow at 8-12%/year to > 2.2 MBPD**

Key: Overlaying Sustainability Criteria on Alternatives (GHG, water etc.)

Source: IEA, 2008

Biofuels Overview: Technology Pathways



Current biofuel market based on sugars & oils. Use bridging feedstocks to get to 2nd Gen feeds – Algae & Lignocellulosics

Ecofining™ Green Diesel

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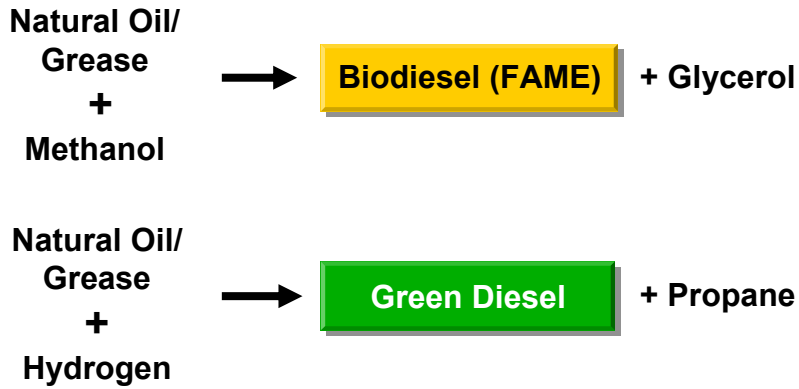
- Superior technology that produces diesel, rather than an additive
- Uses existing refining infrastructure, can be transported via pipeline, and can be used in existing automotive fleet
- Two units licensed in Europe with first commercial start-up in 2010
- Excellent blending component, allowing refiners to expand diesel pool by mixing in "bottoms"
- Excellent results from carmaker tests

Process Comparison vs. Biodiesel



Performance Comparison

	Petrodiesel	Biodiesel	Green Diesel
NOx	Baseline	+10	-10 to 0
Cetane	40-55	50-65	75-90
Cold Flow Properties	Baseline	Poor	Excellent
Oxidative Stability	Baseline	Poor	Excellent

Green Jet Fuel
(Bio Synthetic Paraffinic Kerosene)

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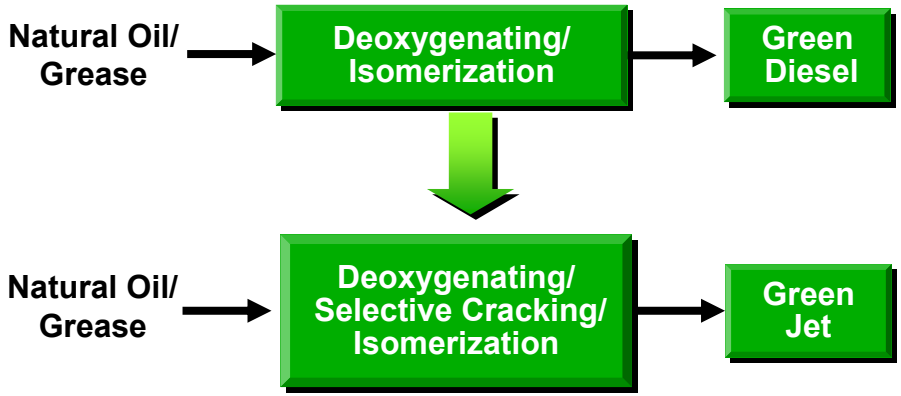
- DARPA-funded project to develop process technology to produce military jet fuel (JP-8) from renewable sources
- Leverages diesel Ecofining process technology for jet fuel
- Green Jet Fuel can meet all the key properties of petroleum derived aviation fuel, flash point, cold temperature performance, etc.
- Extend to commercial aircraft

Built on Ecofining Technology



DARPA Project Partners

Southwest Research Institute
Sandia National Laboratories
DARPA
Cargill
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Honeywell
Air Force Research Laboratory

Key Properties of Green Jet

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Description	Jet A-1 Specs	Jatropha Derived SPK	Camelina Derived SPK	Jatropha/ Algae Derived SPK
Flash Point, °C	**Min 38**	**46.5**	**42.0**	**41.0**
Freezing Point, °C	**Max -47**	**-57.0**	**-63.5**	**-54.5**
JFTOT@300°C				
Filter dP, mmHg	max 25	0.0	0.0	0.2
Tube Deposit Less Than	< 3	1.0	<1	1.0
Net heat of combustion, MJ/kg	min 42.8	44.3	44.0	44.2
Viscosity, -20 deg C, mm^2/sec	max 8.0	3.66	3.33	3.51
Sulfur, ppm	max 15	<0.0	<0.0	<0.0

- **Over 6000 US Gallons of SPK made using UOP process**

BOEING

Production Viability Demonstrated
Fuel Samples from Different Sources Meet Key Properties

Completed Flight Demonstrations

- Successful ANZ Flight Demo Date: December 30 2008

- Successful CAL Flight Demo Date: Jan. 7 2009

- Successful JAL Flight Demo Date: Jan. 30 2009

Algae – Multiple Sources for Fuels

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aquaflow

Wild Algae

Low Production Costs

Sapphire Energy

Enhanced Algae Strains

Moderate Production Cost

Moderate Pre-Treatment Costs

solazyme

Heterotrophically Grown Algae

Moderate Production Costs

High Pre-Treatment Costs

Ecofining™

Low Pre-Treatment Costs

Green Fuels
Gasoline – Jet - Diesel

UOP Renewables Vision

- Produce real fuels instead of fuel additives/blends
- Leverage existing refining, transportation, energy, biomass handling infrastructure to lower capital costs, minimize value chain disruptions, and reduce investment risk.
- Focus on path toward second generation feedstocks & chemicals

Oxygenated Biofuels

Ethanol

Biodiesel

Renewable Energy

Fuel & Power

Hydrocarbon Biofuels

Diesel

Jet

Gasoline

Other Oils: Camelina, Jatropha

First Generation

Natural oils from vegetables and greases

Second Generation

Lignocellulosic biomass, algal oils

Fatty Acid Profile of Algal Oils Tested at UOP

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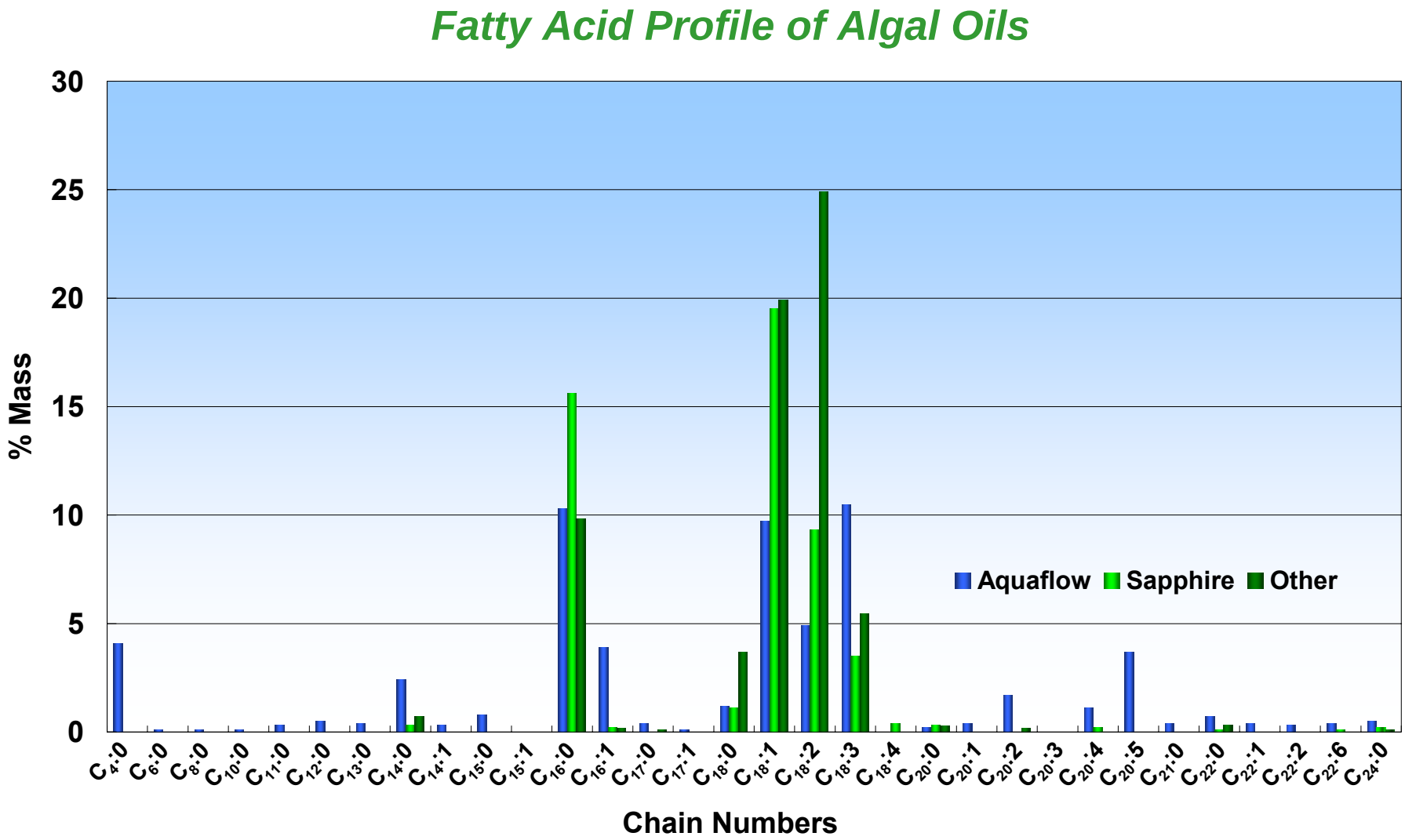

Solazyme Algal Oil: Processing

- Solazyme algal oil composition is very similar to other natural fats and oils processed successfully
- As received Solazyme algal oil processed in pilot plant
- Processed under typical stage 1 (deoxygenation) conditions
- Plant started up with vegetable oils then switched to Solazyme algal oil – direct comparison

Properties of Solazyme Green Diesel

Density (g/ml)	0.78
API gravity	49.8
Sulfur, ppm	12
Nitrogen ppm	<2
Flash, °C	65.5
Cloud point, °C	-4
Pour point, °C	-6
CFPP, °C	-8

Solazyme Algal Oil Can be Converted to "True" Diesel Fuel at High Yield With Desirable Properties

Sapphire Algal Oil: Processing

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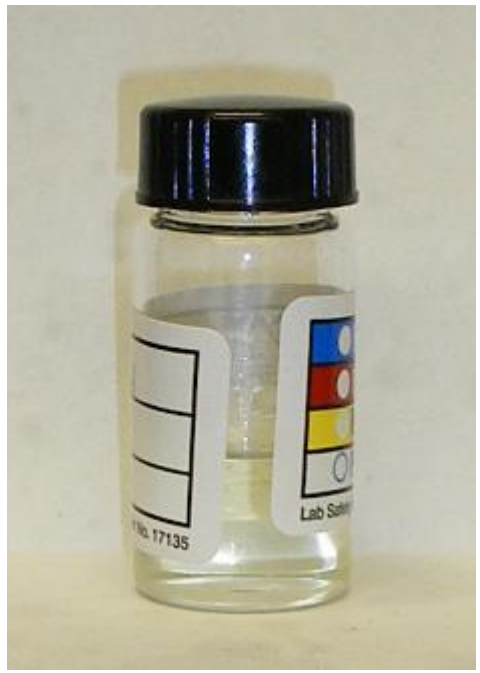
Sapphire Energy

- Deoxygenation: Standard conditions
- Clear, colorless product, deoxygenation essentially complete
- Product difference relative to soybean oil paraffin reflective of feedstock *and* processing variables

Component	*Typical Soy Product (mass %)*	*Sapphire Algal Oil Product (Mass %)*
$<C_{15}$	0.9	2.1
C_{15} iso	<0.1	1.1
C_{15} n	3.2	12.3
C_{16} iso	0.1	1.7
C_{16} n	6.6	12.8
C_{17} iso	1.0	2.1
C_{17} n	29.2	30.0
C_{18} iso	2.2	2.3
C_{18} n	54.7	29.8
$>C_{18}$	2.1	5.7



Aquaflow Deoxygenation Product

Component	Typical Product (mass %)	Algal Oil Product (Mass %)
$<C_{15}$	0.9	6.8
C_{15} iso	<0.1	1.8
C_{15} n	3.2	12.4
C_{16} iso	0.1	1.7
C_{16} n	6.6	13.6
C_{17} iso	1.0	3.0
C_{17} n	29.2	14.6
C_{18} iso	2.2	*10.5*
C_{18} n	54.7	14.6
$>C_{18}$	2.1	*21.6*

- Crude Algal oil deoxygenated (98+%) in laboratory autoclave reactor
- More heavy hydrocarbon than typical oil feeds observed

Integrated Algal Biorefinery

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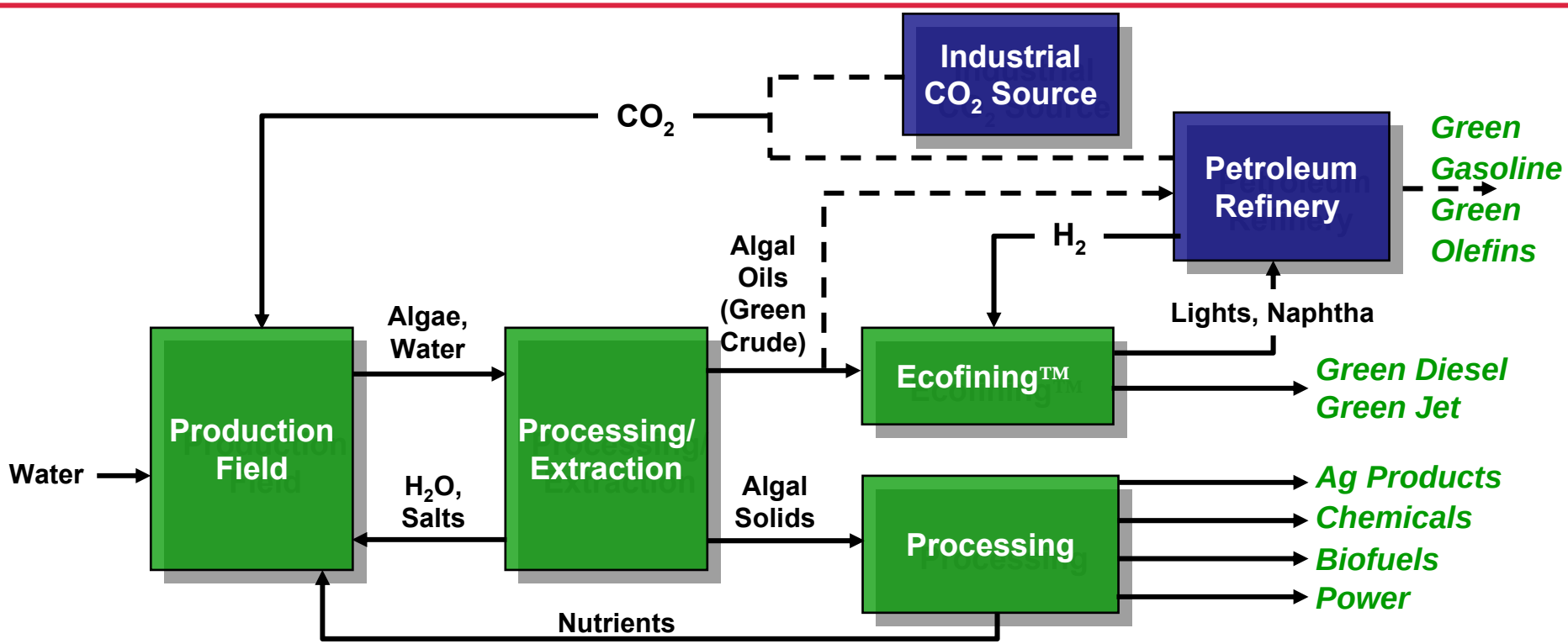

INPUTS

- CO_2, waste N
- Brackish water
- Acres non-arable land
- SCFD Hydrogen

OUTPUTS

- Algal oil or paraffins
- Solids (Food, Fuel, Chemicals)
- Green Diesel/Jet or other biofuels
- Remaining products defined by refinery configuration
- Power output defined by system economics

Maximize Total Product Value
Cross Industry Overlay

Scope of Jet Fuel WTW* LCA

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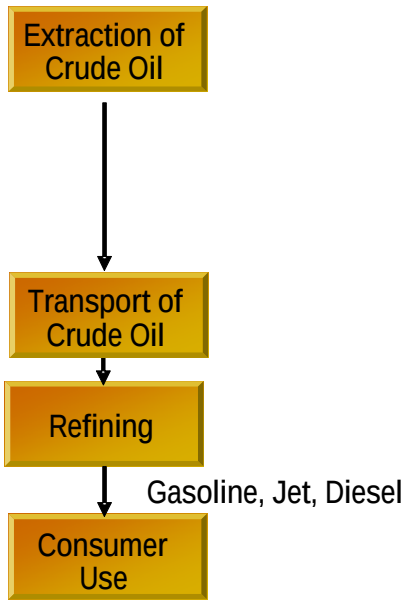
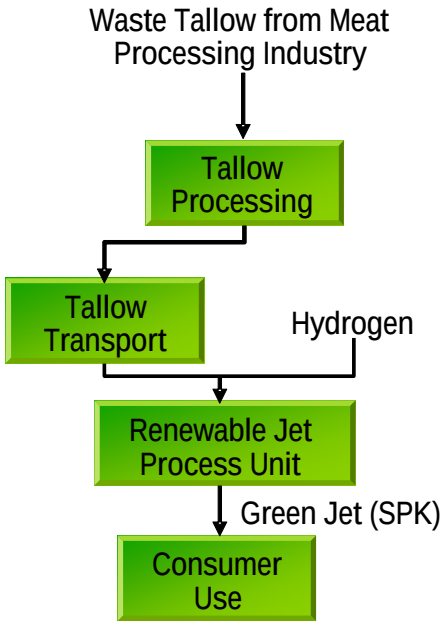
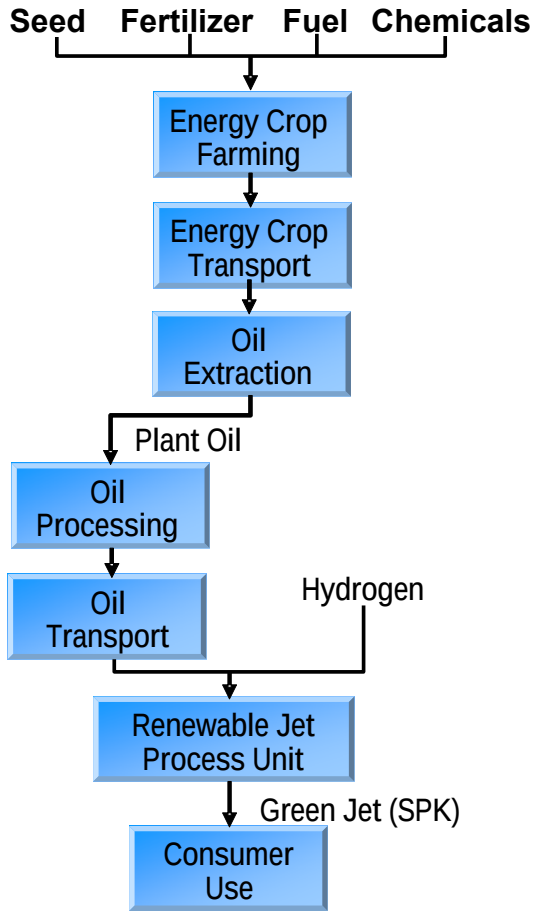
Petroleum Based Fuels



Green Jet from Waste Tallow



Green Jet from Energy Crops



***WTW for jet fuel is "well-to-wake "**

Life Cycle Analysis for Bio-SPK

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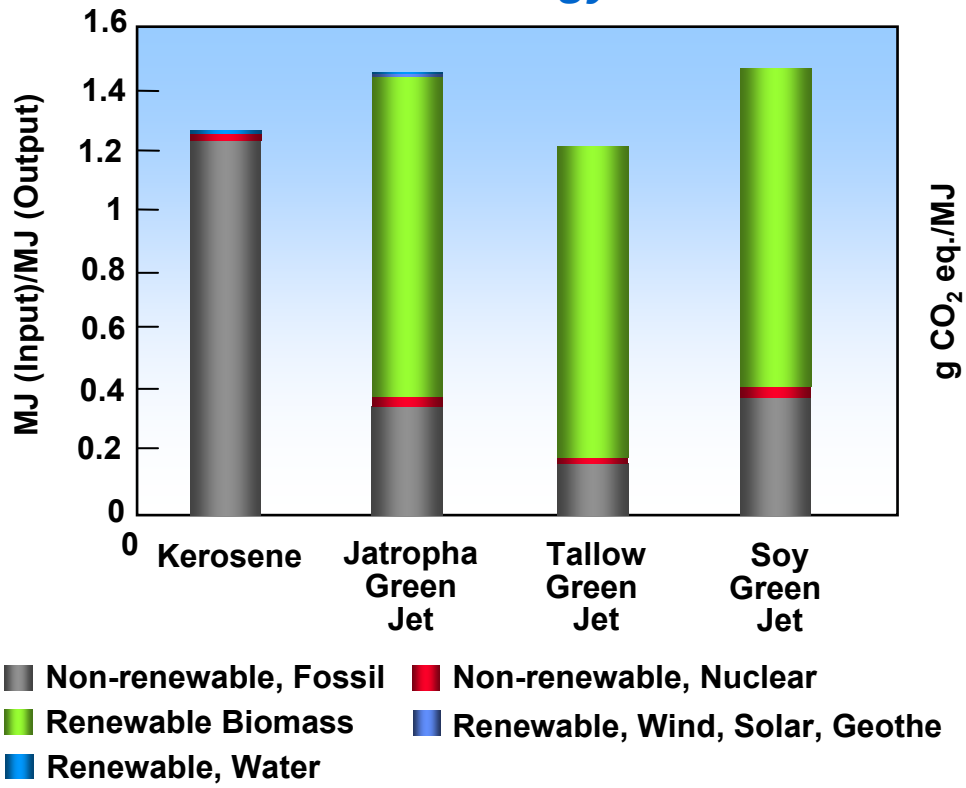
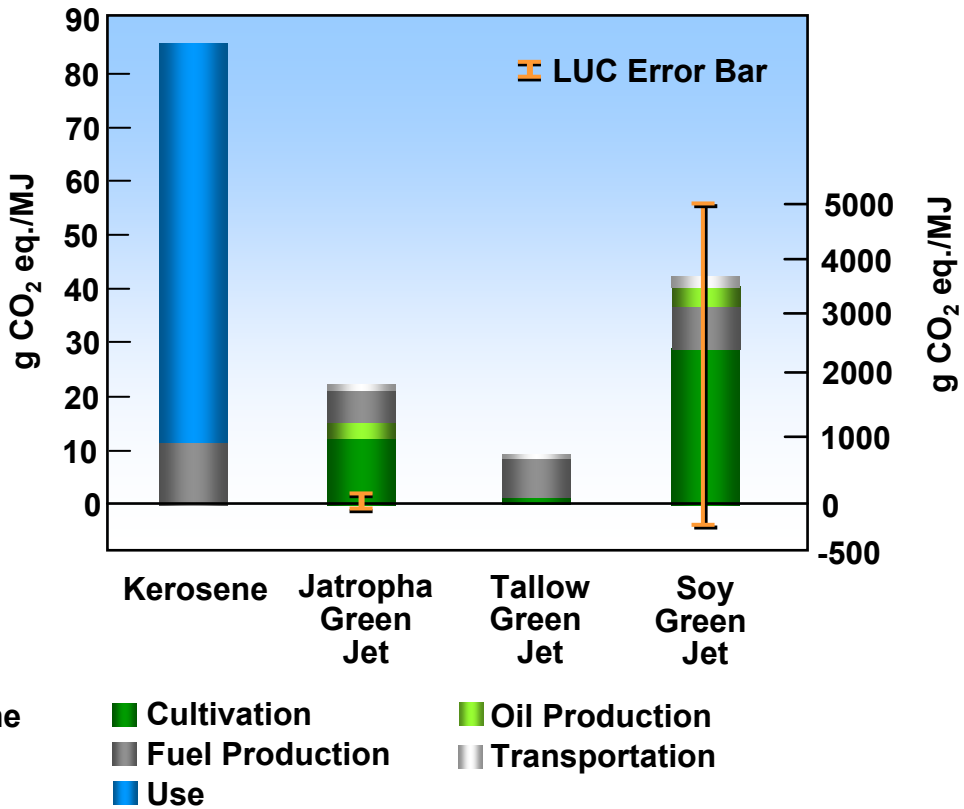
Cumulative Energy Demand



Greenhouse Gases



Significant GHG Reduction Potential

Basic Data for Jatropha Production and Use. **Reinhardt, Guido et al.** IFEU June 2008
Biodiesel from Tallow. **Judd, Barry.** s.l. : Prepared for Energy Efficiency and Conservation Authority, 2002.
Environmental Life-Cycle Inventory of Detergent-Grade Surfactant Sourcing and Production. **Pittinger, Charles et al.** 1, Prarie Village, Ka : Journal of the American Oil Chemists' Society, 1993, Vol. 70.

UOP Renewables Vision

- Produce real fuels instead of fuel additives/blends
- Leverage existing refining, transportation, energy, biomass handling infrastructure to lower capital costs, minimize value chain disruptions, and reduce investment risk.
- Focus on path toward second generation feedstocks & chemicals

Oxygenated Biofuels

Ethanol

Biodiesel

Renewable Energy

Fuel & Power

Hydrocarbon Biofuels

Diesel

Jet

Gasoline

Other Oils: Camelina, Jatropha

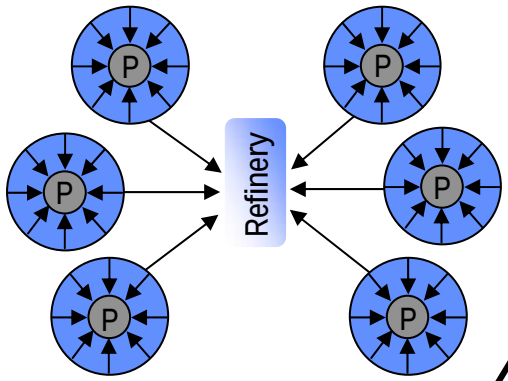
First Generation

Natural oils from vegetables and greases

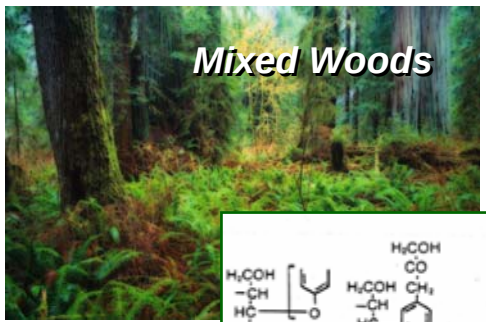
Second Generation

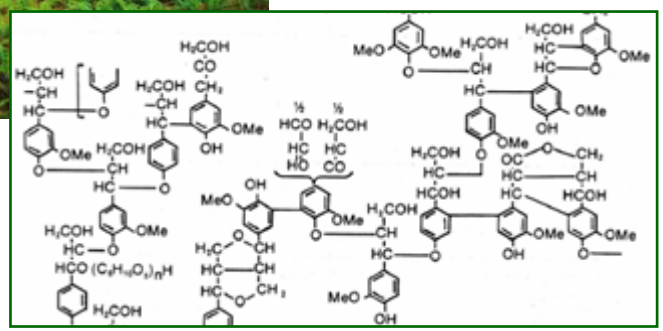
Lignocellulosic biomass, algal oils

Pyrolysis Oil to Energy & Fuels Vision



Biomass → Fast Pyrolysis → Pyrolysis Oil





- Electricity Production
- Fuel Oil Substitution

Available Today

- Transport Fuels (Gasoline, Jet Diesel)
- Chemicals (Resins, BTX)

3 Years to complete R&D

Transport Fuels already achieved on lab-scale
Collaboration with DOE, NREL, PNNL, USDA

UOP / Ensyn Joint Venture

Envergent TECHNOLOGIES
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- Announced September 2008
- Pyrolysis Oil technology for fuel oil substitution & electricity generation now available
- JV becomes channel for UOP R&D results on upgrading pyrolysis oil to transport fuels

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- Core competence in engineering and technology scale-up
- Co-inventor of Fluidised Catalytic Cracking (FCC) technology
- Modular process unit supplier
- Leader in fundamental catalyst and process development (Upgrading)

ENSYN

- ~20 years of commercial fast pyrolysis operating experience in food industry
- Developers of innovative RTP fast pyrolysis process
- 8 commercial RTP units designed for food application
- Now applying technology to fuel oil and energy

2nd Gen Renewable Energy Company – Global Reach

Rapid Thermal Process (RTP™) Technology

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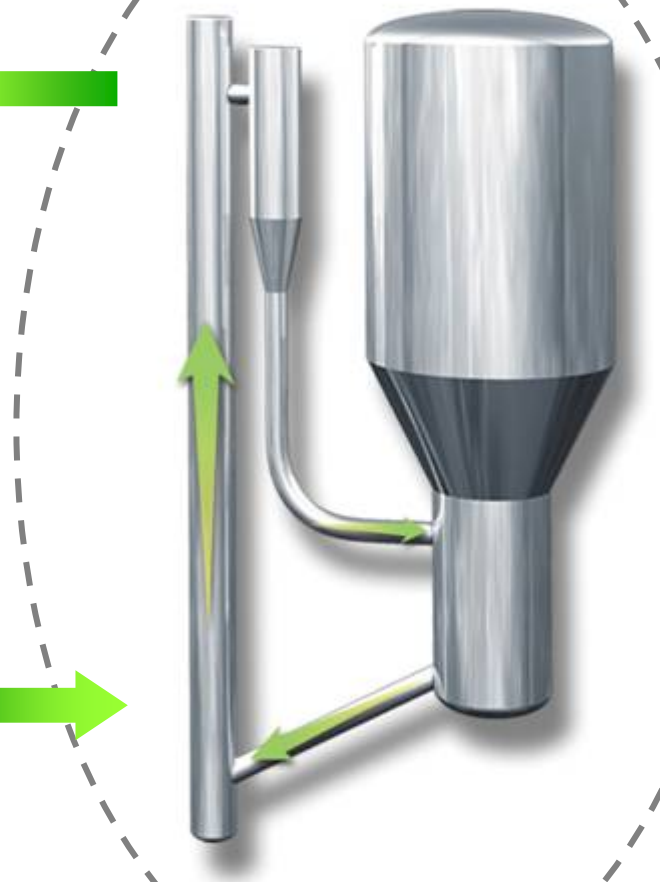
Pyrolysis Oil

Solid Biomass



- 510°C, <2 secs
- Biomass converted to liquid pyrolysis oil
- Fast fluidized bed, sand as heat carrier
- High yields; >70 wt% liquid on woody biomass
- Light gas and char by-product provide heat to dry feed and operate unit

Proven Technology, full scale designs available

RTP™ Pyrolysis Oil Properties

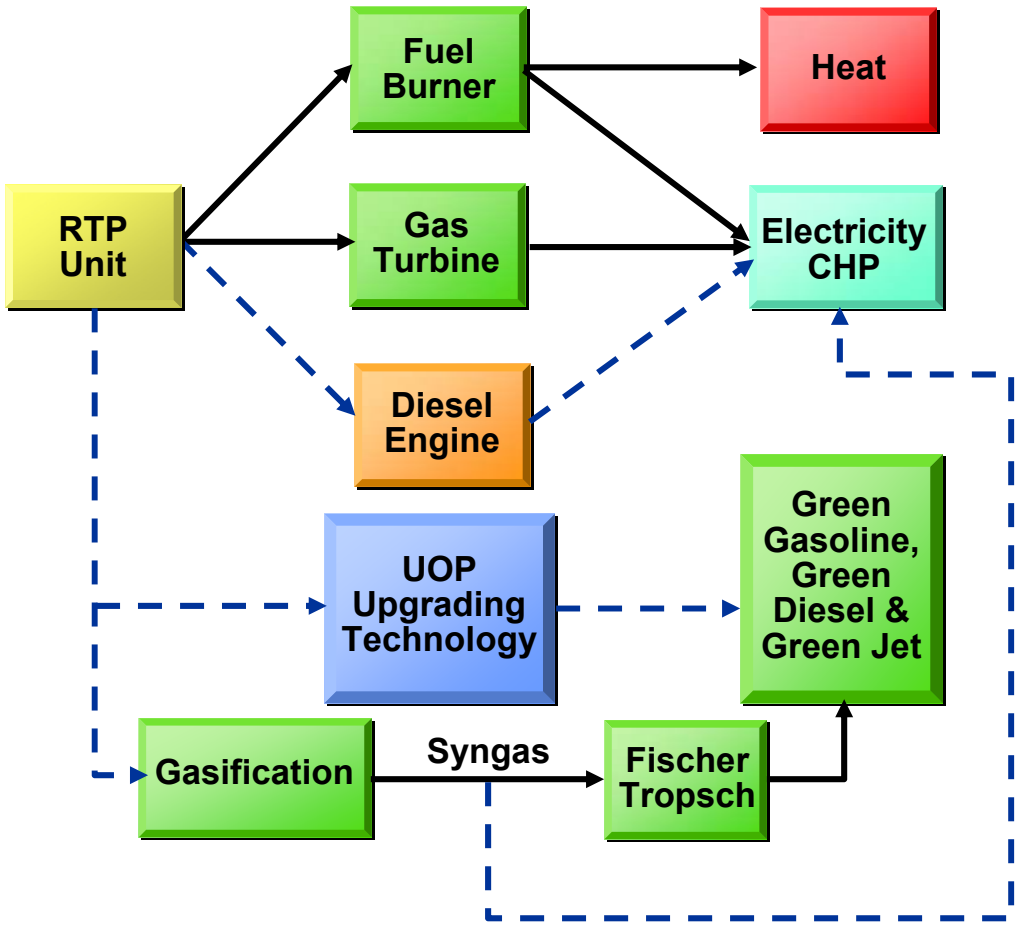
- Contains ~60% the energy content of crude-based fuel oils
- High viscosity and acidity
- ~40% oxygen content
- Pourable and transportable liquid fuel

Comparison of Heating Value of Pyrolysis Oil and Typical Fuels

Fuel	MJ / Litre	BTU / US Gallon
Methanol	17.5	62,500
Pyrolysis Oil (Wood)	21.0	75,500
Pyrolysis Oil (Bark)	22.7	81,500
Ethanol	23.5	84,000
Light Fuel Oil / Diesel	38.9	138,500

Pyrolysis Oil is cost effective with Light Fuel Oil on an energy basis

Pyrolysis Oil Applications



- Current Applications
- Emerging Applications

Early Applications Proven. A GHG Emission Reduction Solution for Industrial Sites

Achieving Sustainability

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- Renewables are going to make up an increasing share of the future fuels pool
  - Multitude of bioprocessing approaches possible
  - Fungible biofuels are here
  - Essential to overlay sustainability criteria
- First generation biofuels, though raw material limited, are an important first step to creating a biofuels infrastructure. Bridging feedstocks are key.
- Second generation feedstocks, cellulosic waste and algal oils, have the potential to make significant contributions.
- Important to promote technology neutral and performance based standards and directives to avoid standardization on old technology.

Create a Portfolio of Options

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감사합니다

Спасибо

Thank You

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جزاكم الله خيراً

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